CHAPTER 3 - GEOLOGY AND HYDROLOGY

INTRODUCTION

Montana is the site of the juxtaposition of the Great Plains with the Rocky Mountains. The rocks at the surface vary from the ancient metamorphic and igneous complexes forming the cores of some mountains to Recent sediments in the major river valleys of the state. Geology of Montana plays an indispensable role in forming the mineral resources, visual resources, and water resources of the state. The geologic history of the state has been a series of major structural events in the tectonics, or continent building of North America.

Exhibit 7 is the Tectonic Element Map of the State of Montana. The map shows the locations of important basins such as the Big Horn and Williston that have trapped sediment containing coal, oil, and natural gas. The map also locates mountain ranges such as the Crazy Mountains and Black Hills that served as sources for some of the sedimentary units. Several tectonic elements will be discussed in detail throughout this Technical Report including those features that affect the state's resources – The Powder River Basin, The Big Horn Basin, Big Horn Mountains, the Bull Mountains Basin, and others. These major tectonic elements control the porous reservoirs that hold the usable water, oil, and natural gas. They also control the impermeable barriers to fluid movement. These elements also control the local folds and faults that form the oil and gas fields of the state.

Montana's basins have accumulated sediments several miles in thickness; these sands, shales, and limestones form the source and reservoirs of Montana's fossil energy reserves – crude oil, natural gas, coal, and coal bed methane (CBM). In these basins, ancient sediments were buried to great depths within the earth where heating and increased pressure formed the fuels from the raw plant materials trapped in the sediments. The sedimentary basins also hold a significant portion of the water resources of the state; in the deep parts of these basins the water is generally salty while the shallower parts of these basins there is fresh water of meteoric origin.

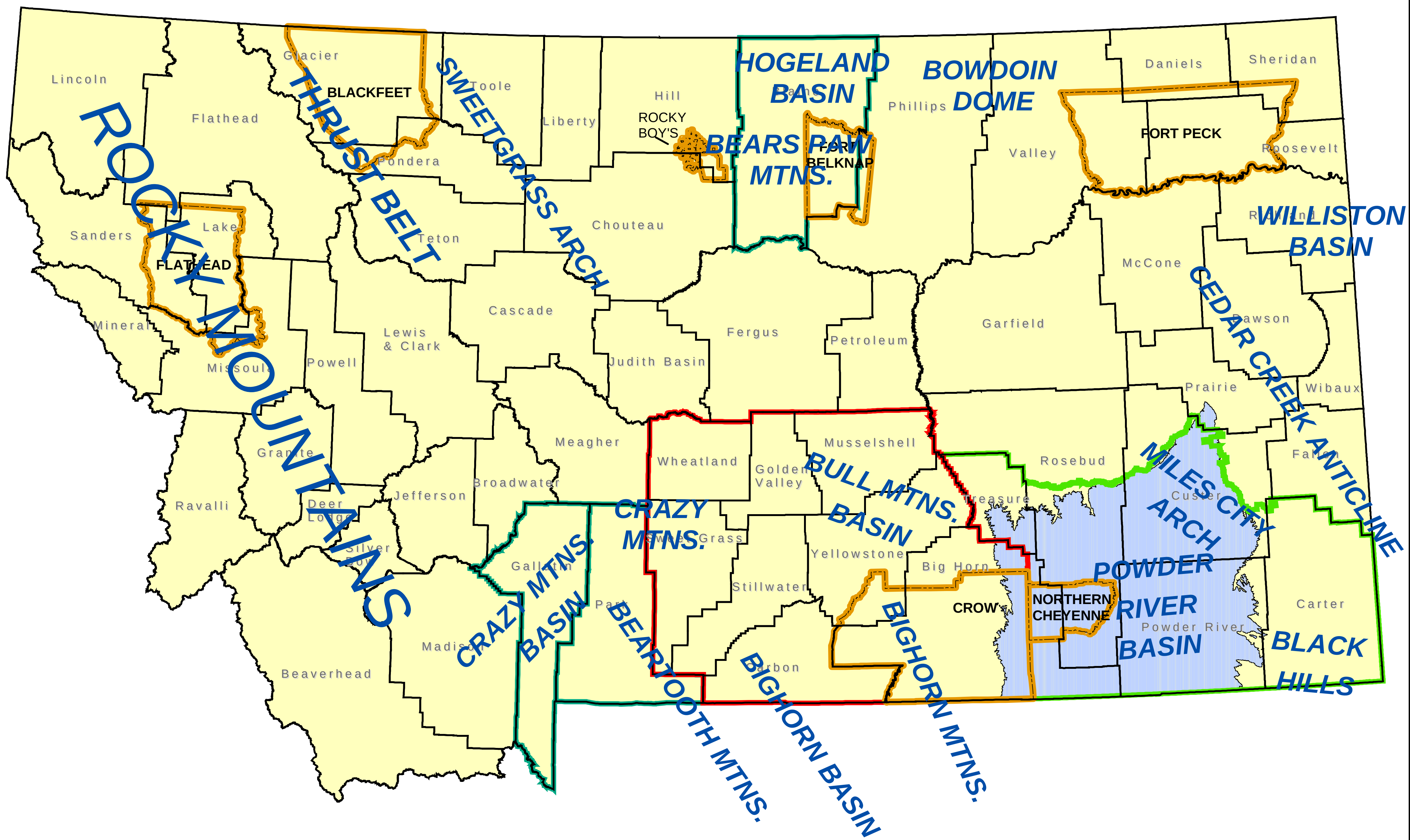
Exhibit 8 presents a map of the statewide outcrop geology. The map emphasizes broad basin features underlying the Great Plains in contrast to the intensely contorted structures under the many mountain areas. The basins mentioned above as likely to contain CBM resources, such as the PRB, can be seen as broad expanses of similar outcrop. In the case of the PRB, rocks at the surface are all coal-bearing Tertiary formations except for the scattered Quaternary age Alluvium in stream and river valleys. Other basins contain coal-bearing sediments of Cretaceous age. The presence of large volumes of suitable coal is vital for predicting CBM development.

CBM is the focus of this EIS; its exploration and production is discussed in Chapter 2 and it is important to recognize that the resource is intimately associated with coal deposits. The methane gas is generated by the coal deposit both under thermogenic (heat-driven) and biogenic (microbe-driven) conditions. At the same time, the methane is trapped in the coal seams by the pressure of groundwater. Releasing the pressure of groundwater from the coal aquifers liberates methane, allowing it to be produced and sold. The magnitude of the CBM resource is determined by coal type and volume; the location of coal reserves will predict the location of Montana's CBM resources.

Exhibit 9 is the statewide coal occurrence map. The map displays the extent of coal deposits that support mines and are expected to support projected CBM development. The geology of Montana has given rise to several different kinds of coal; the most important differentiator is coal rank or thermal maturity. As coal is buried or otherwise heated, the raw plant material is gradually converted from complex carbon compounds to simple compounds and elemental carbon. Exhibit 9 highlights coal rank or maturation ranging from lignite, sub-bituminous, high-volatile bituminous, medium-volatile bituminous, low-volatile bituminous, and anthracite coals (Leythaeuser and Welte, 1969). The areas of interest are the PRB, Bull Mountain Basin, and Blaine County, which contain mostly sub-bituminous coal that has not reached a high degree of maturation. Also of interest for CBM are the Big Horn Basin and the counties of Park and Gallatin that contain medium and high volatile bituminous coal of slightly higher maturity.

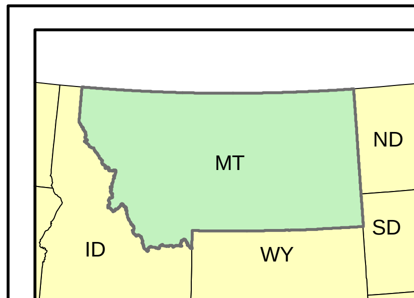
Exhibit 10 shows the cereal extent of the PRB throughout Montana and Wyoming as current CBM development. Analysis of this exhibit shows that over half of the basin is located in Wyoming. The exhibit emphasizes the increase in drilling throughout the entire basin after 1997. The map also highlights the lack of drilling in the Montana portion of the PRB.

Exhibit 7: Tectonic Element Map of the State of Montana



Legend

- Billings RMP Area
- Powder River RMP Area
- Special Consideration Counties
- Native American Reservations
- Powder River Geologic Basin



Location Map

Date Prepared: April 2, 2001

Prepared by: J. Patton

Project Mgr.: D. Arthur

N W E S

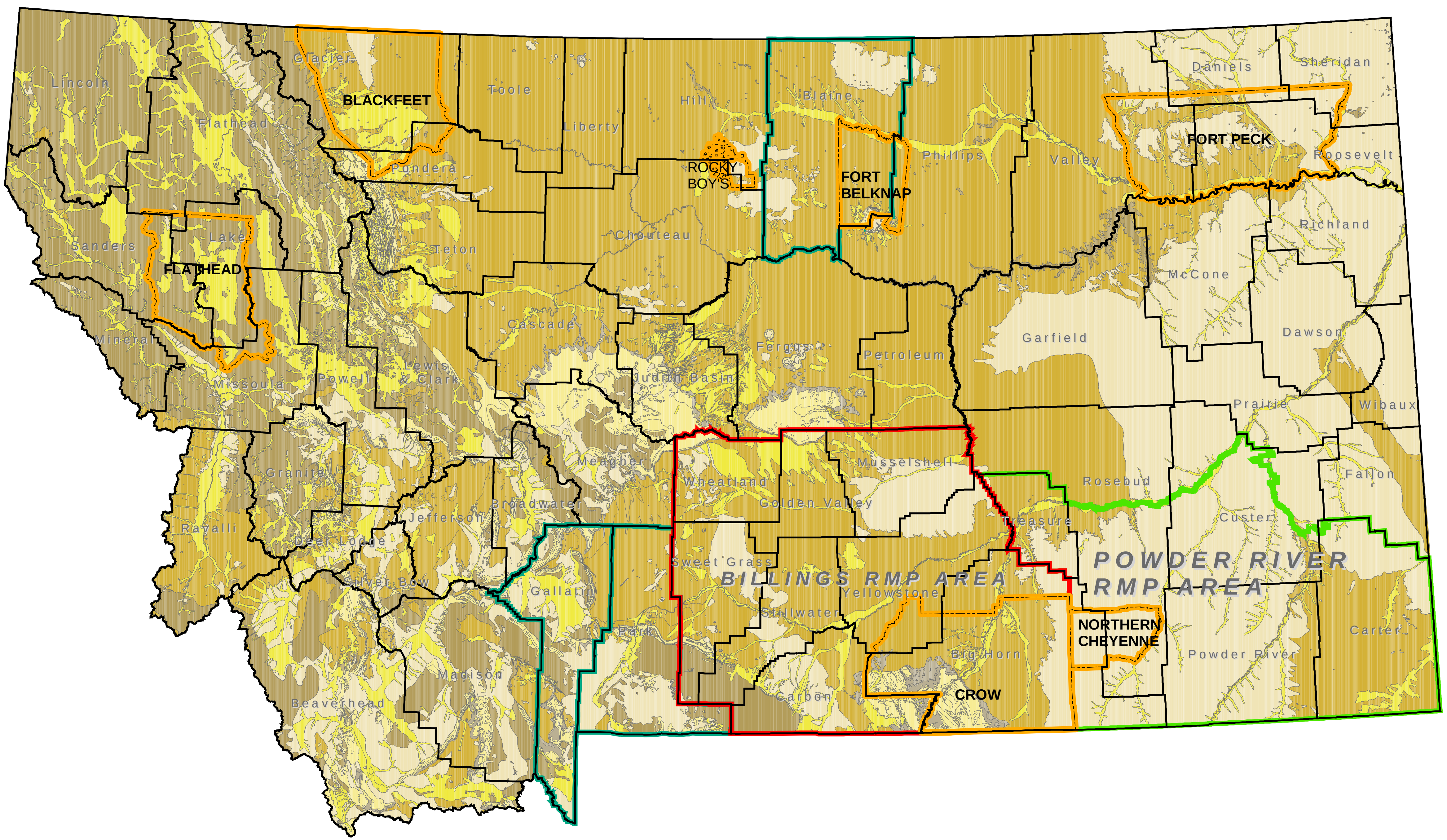
1:3,200,000

50 25 0 50 Miles

50,000 25,000 0 50,000 100,000 Meters

DATA SOURCES:
Tectonic Elements: Cohee et al, 1962.
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana.
Reservations: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana.
Powder River Geologic Basin: 1:250,000 scale, USGS Professional Paper 1625a.

Exhibit 8: Statewide Outcrop Geology

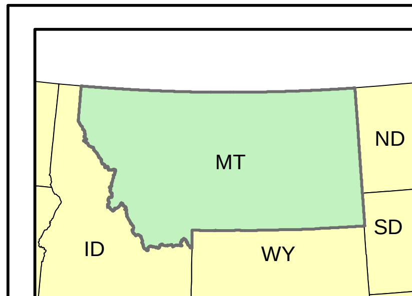


Legend

- Billings RMP Area
- Powder River RMP Area
- Special Consideration Counties
- Native American Reservations

GEOLOGIC SYSTEM

- Quaternary
- Tertiary
- Cretaceous
- Triassic
- Paleozoic
- Unknown



Location Map

Date Prepared: April 2, 2001

Prepared by: J. Patton

Project Mgr.: D. Arthur

1:3,000,000

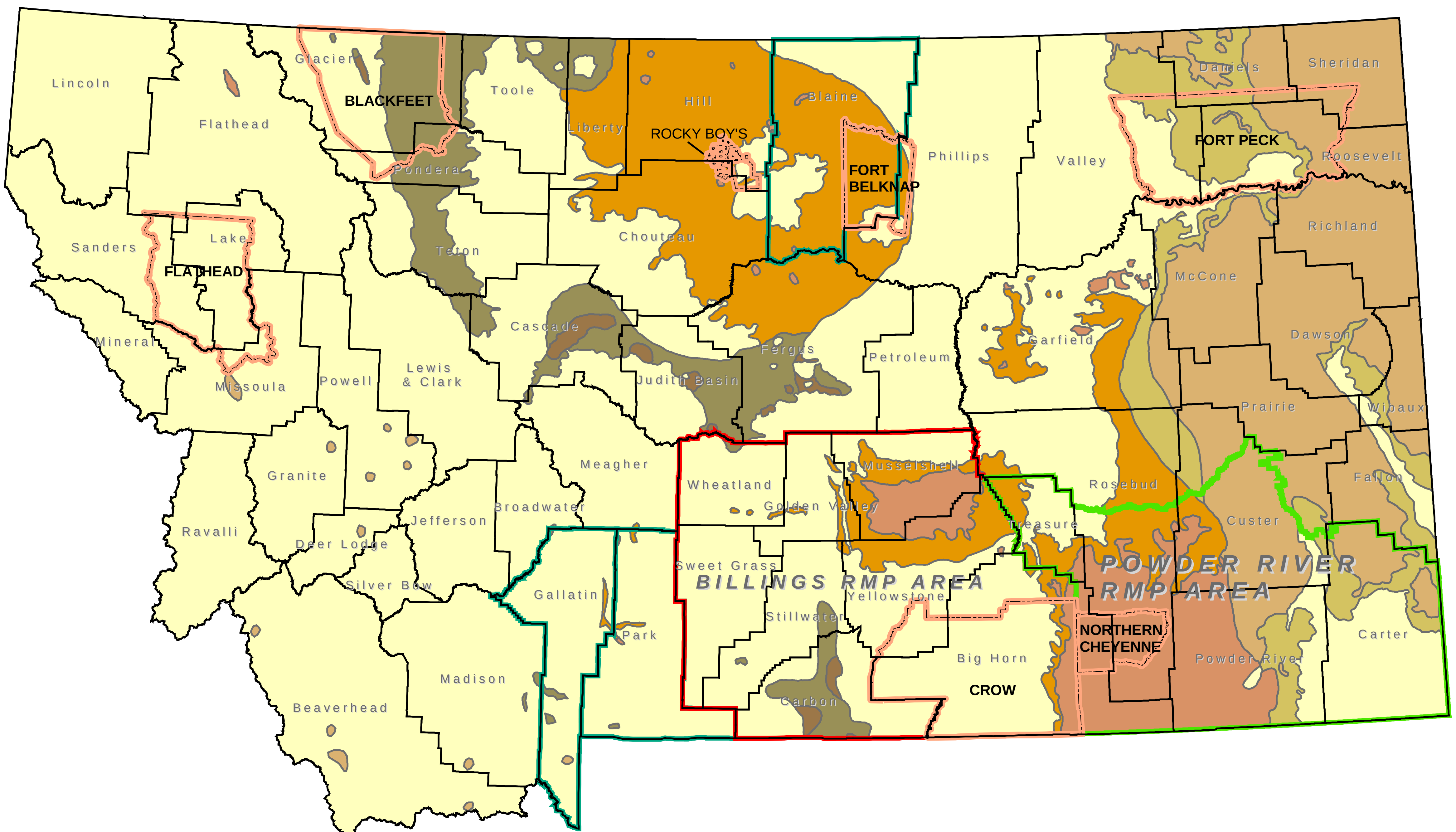
50 25 0 50 Miles

50,000 25,000 0 50,000 100,000 Meters

DATA SOURCES

Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana
Geology: 1:1,000,000 scale, geology, Montana State Library/NRIS, Helena, Montana
RMP Areas: BLM Miles City Field Office

Exhibit 9: Statewide Coal Occurrence Map

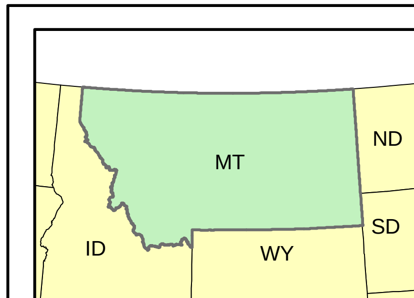


Legend

- Billings RMP Area
- Special Consideration Counties
- Powder River RMP Area
- Native American Reservations

GENERALIZED COAL RANK

- Lignite
- Lignite of doubtful value
- M-H Volatile Bituminous
- M-H Volatile Bituminous of doubtful value
- Sub-Bituminous
- Sub-Bituminous of doubtful value



Location Map

Date Prepared: April 2, 2001

Prepared by: J. Patton

Project Mgr.: D. Arthur

1:3,000,000

50 25 0 50 Miles

50,000 25,000 0 50,000 100,000 Meters

DATA SOURCES

Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana
RMP Areas: BLM Miles City Field Office.
Coal Occurrence: Tully, 1996.

NOTE: To be used as a reference graphic only. Coal Occurrence data originated from 1:5,000,000 scale data.

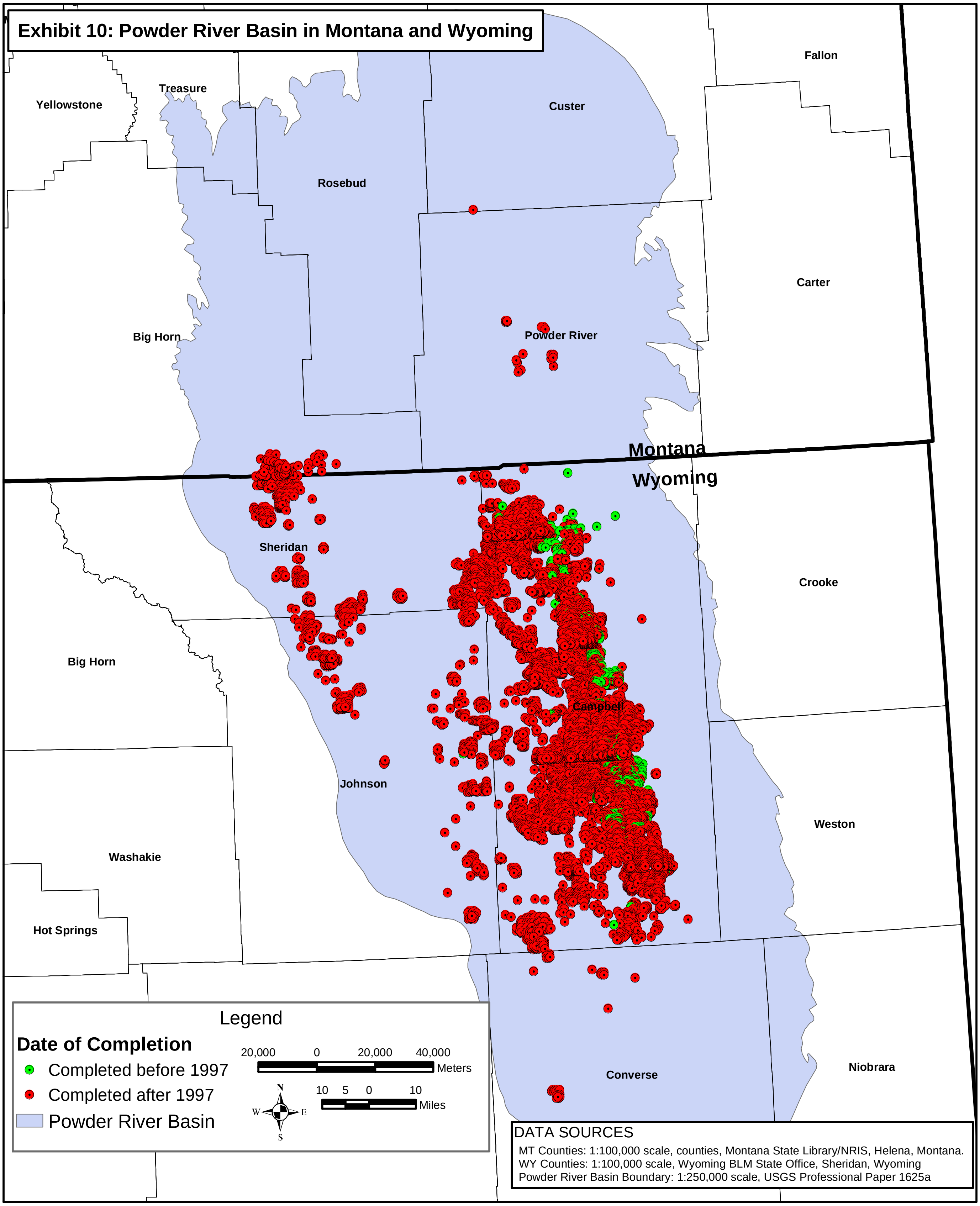


Exhibit 10: Powder River Basin in Montana and Wyoming
Fallon
Treasure
Yellowstone
Custer
Rosebud
Carter
Big Horn
Powder River
Montana
Wyoming
Sheridan
Crooke
Big Horn
Campbell
Johnson
Weston
Washakie
Hot Springs
Converse
Niobrara
Legend
Date of Completion
Completed before 1997
Completed after 1997
Powder River Basin
20,000 0 20,000 40,000
Meters
10 5 0 10
Miles
N
W
E
S
DATA SOURCES
MT Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana.
WY Counties: 1:100,000 scale, Wyoming BLM State Office, Sheridan, Wyoming
Powder River Basin Boundary: 1:250,000 scale, USGS Professional Paper 1625a

According to the Montana Board of Oil and Gas Conservation (MBOGC) records, CBM has been produced only in the CX Ranch field in the Montana portion of the PRB since April 1999. Exploration solely for CBM first happened in the Montana PRB in December 1990 in the area of CX Ranch. However, the first CBM exploration in the state was in August 1990 in the Big Horn Basin where CBM was tested but never sold. In many parts of the state, coals are aquifers that contain significant amounts of groundwater and are used by residents for water needs. In order to produce the methane in the Montana part of the PRB, groundwater must be drawnoff the coal aquifer. Unless groundwater is produced from the coals, methane will not be produced; water production cannot be avoided during CBM development. This is the central conflict between CBM and traditional uses of the land; when CBM is produced, local coal aquifers are partially depleted. Depending on the area, this depletion may extend beyond the CBM producing field boundaries.

REGIONAL GEOLOGY

The planning area of the EIS centers on the Powder River RMP area and the Billings RMP area. The planning area contains three major basinal features – Powder River, Big Horn, and Bull Mountains – and surrounding uplifted areas. All three basins were formerly broad shelf areas until Laramide tectonics caused uplift in the surrounding features and this uplift contributed to sedimentary subsidence within the basins during the Late Cretaceous and Early Tertiary. The Bull Mountains Basin and PRB were one continuous basin during the depositional periods of the Cretaceous and Early Tertiary. It was post-depositional tectonics that divided the two (Stricker, 1999). The asymmetric basins are the result of a combination of sedimentary and structural subsidence with most of the fill consisting of the Fort Union Formation. The Fort Union Formation also contains most of the coals occurring in these three basins.

The PRB in its entirety covers approximately 12,000 square miles with the smaller portion in Montana (Ellis et al. 1998). The PRB is bounded to the west by the Bighorn Uplift, to the southwest and south by the Casper Arch, Laramie Mountains, and Hartville Uplift; and to the east by the Black Hills Uplift. The Miles City Arch and the Cedar Creek Anticline to the north essentially separate the PRB from the Williston Basin. Coal has been mined in the PRB since 1865 and large-scale strip-mining has been underway since the mid-1960s when demand increased for relatively clean-burning coals (Flores and Bader 1999). Conventional oil and gas have been exploited in the PRB for more than 50 years while CBM has been only lately developed with major activity beginning in 1997 (Rice et al. 2000).

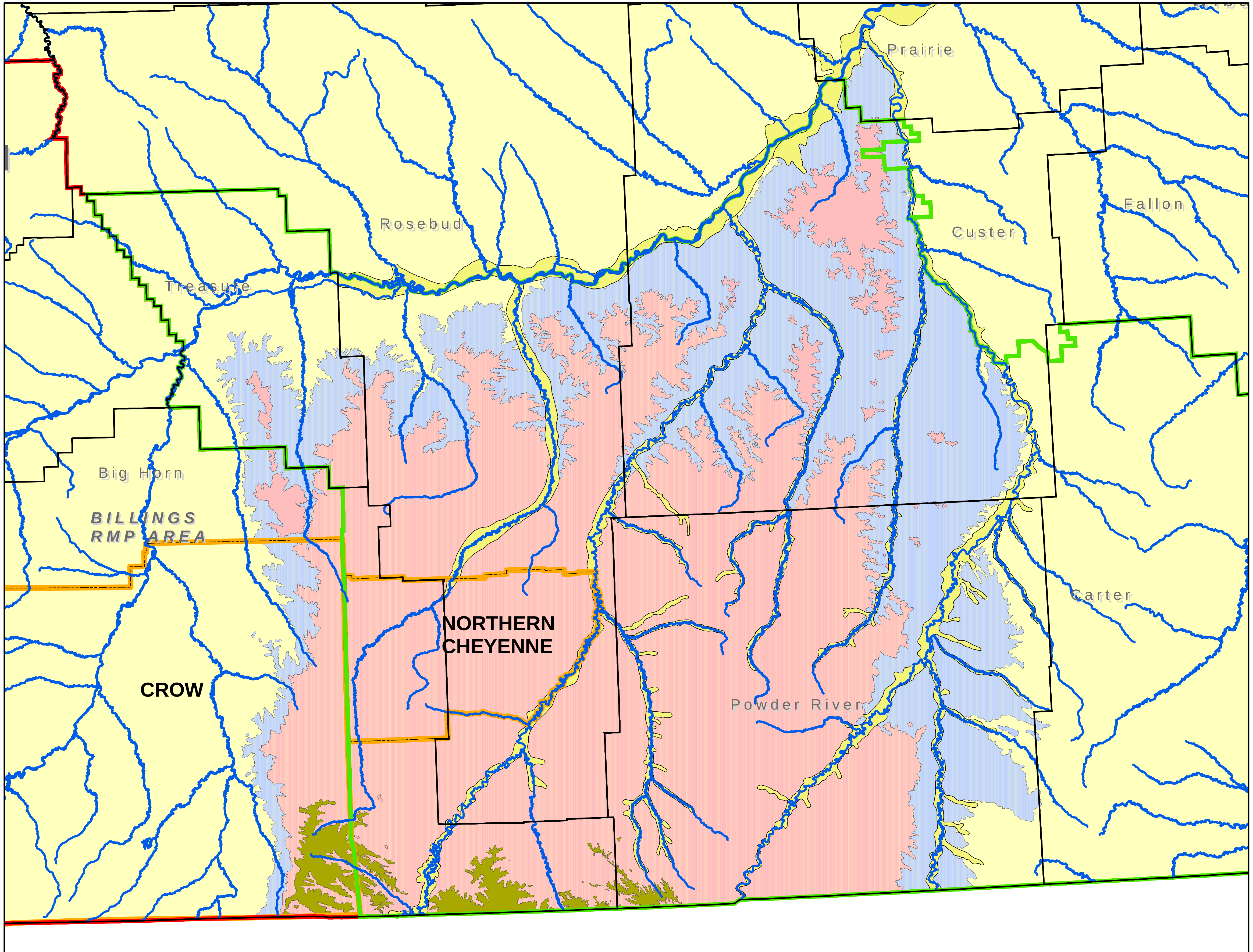
Exhibit 11 depicts the outcrop geology of the Montana portion of the PRB. The map illustrates the broad geometry of the basin with the youngest Tertiary strata (Wasatch Formation) preserved in the deepest part of the basin just north of the Wyoming-Montana state line. The broad bands of the Tongue River and Lebo/Tullock members throughout most of the basin attest to the shallow dips to the east and north edges of the basin. The narrow outcrop bands on the west limb of the basin indicate that the basin is somewhat asymmetrical with steeper dips on the western side. Exhibit 11 also illustrates the scattered distribution of the Alluvium that fills the valleys of the basin.

Exhibit 12 portrays the distribution of water wells, the prospective CBM areas, and existing CBM production within the Montana portion of the PRB. The map was constructed from information in the MBMG Map 60 (Van Voast and Thale, 2001) and emphasizes those areas with thick, sub-bituminous and bituminous coal reserves. Coals are both water reservoirs and gas reservoirs and as such CBM production will affect local aquifers and even surface water. CBM development is expected to be concentrated in the southern portion of the PR RMP area although coals exist over most of the basin and CBM coverage could prove to be greater. The water wells shown in the exhibit could be at risk to drawdown impact from CBM development, especially those water wells completed in coal aquifers. Those aquifers at risk to CBM impact are described in the Hydrology section below.

STRATIGRAPHY

The stratigraphy of the planning area analyzes the age, composition, and continuity of sedimentary rocks. The sedimentary strata of the planning area extend backward in time from recent age alluvium found in stream valleys, to strata at the surface that is largely Tertiary and Cretaceous. These older sediments correspond to the Laramide tectonism that gave rise to most of the uplifted areas in Montana. Though the area contains significant regional thicknesses of older stratigraphic units, the Tertiary basin fills are of particular interest for coal, CBM, and groundwater production (Ellis et al. 1998). Conventional oil and natural gas occur in the older, pre-Laramide section but coals in the PRB are confined to the Early Tertiary units.

Exhibit 11: Outcrop Geology of the Montana Portion of the Powder River Basin

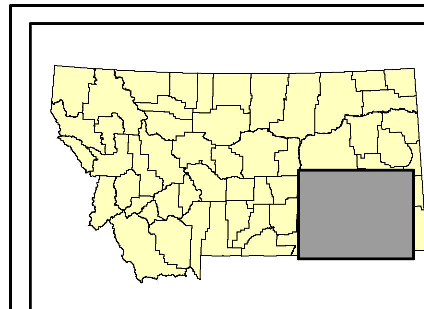


Legend

- Rivers
- Powder River RMP Area
- Billings RMP Area
- Native American Reservations

GEOLOGY

- Alluvium from STATSGO soils
- Wasatch Fm.
- Tongue River Mbr.
- Lebo / Tullock Mbrs.



Location Map

Date Prepared: April 2, 2001

Prepared by: J. Patton

Project Mgr.: D. Arthur

N S W E

1:920,000

20 10 0 20 Miles

20,000 10,000 0 20,000 40,000 Meters

DATA SOURCES

Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana
RMP Areas: BLM Miles City Field Office.
Geology: 1:250,000 scale, 1999, USGS Professional Paper 1625a.

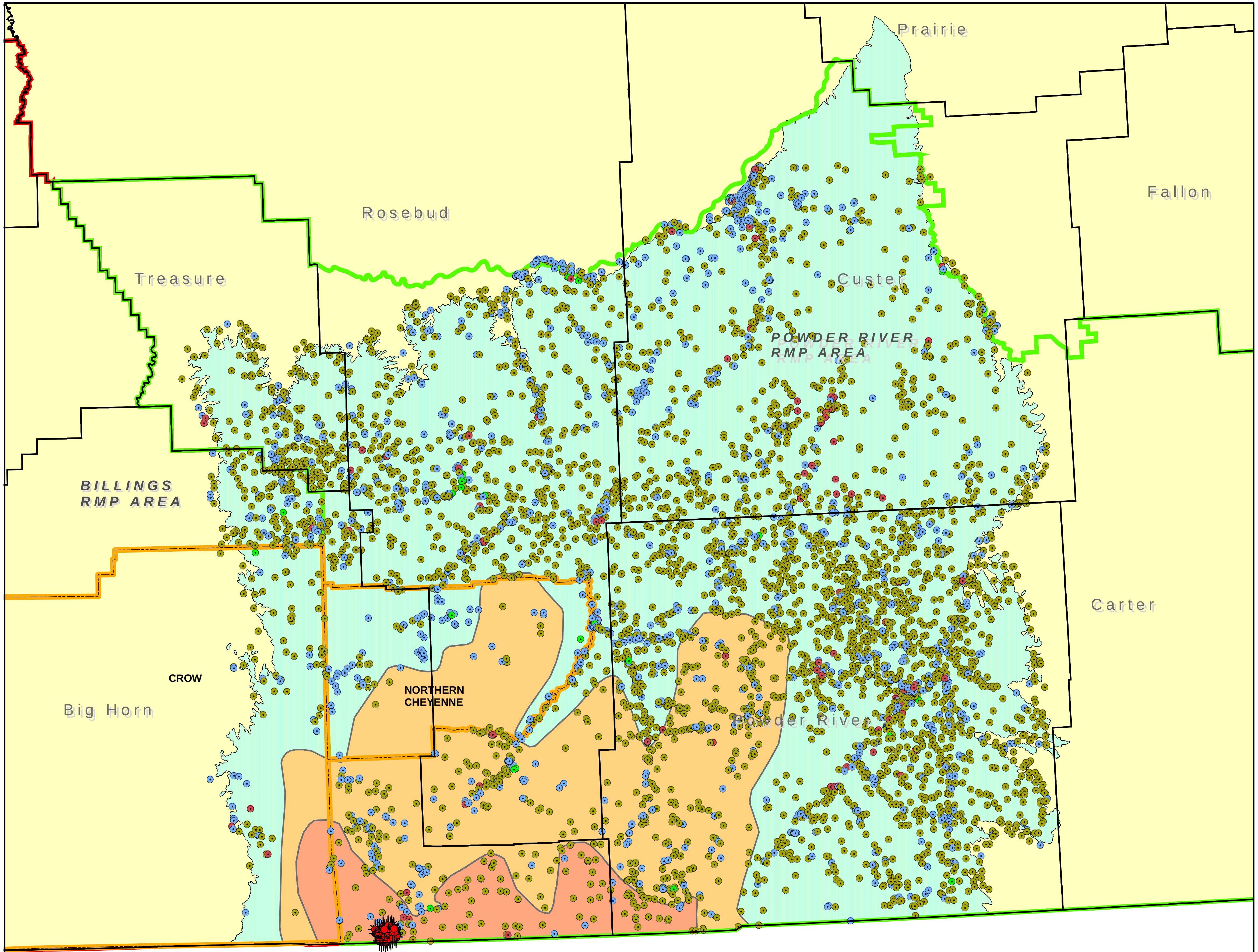


Exhibit 12: CBM Likelihood, Water Well Use, and Current CBM Production in Powder River Basin

Legend

- Powder River RMP Area
- Billings RMP Area
- Powder River Geologic Basin
- Native American Reservations

WELL USE

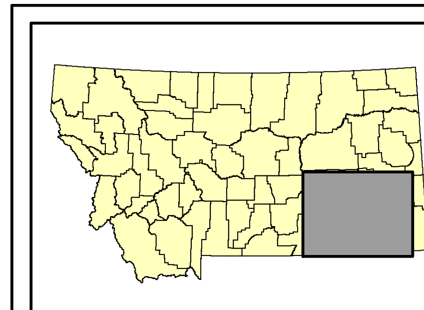
- DOMESTIC
- IRRIGATION
- PUBLIC WATER SUPPLY
- STOCKWATER

PRODUCING CBM WELLS

- CBM

POTENIAL OF CBM DEVELOPMENT

- Higher
- Lower



Location Map

Date Prepared: April 2, 2001

Prepared by: J. Patton

Project Mgr.: D. Arthur

N W E S

1:870,000

10 5 0 10 Miles

10,000 0 10,000 20,000 Meters

DATA SOURCES

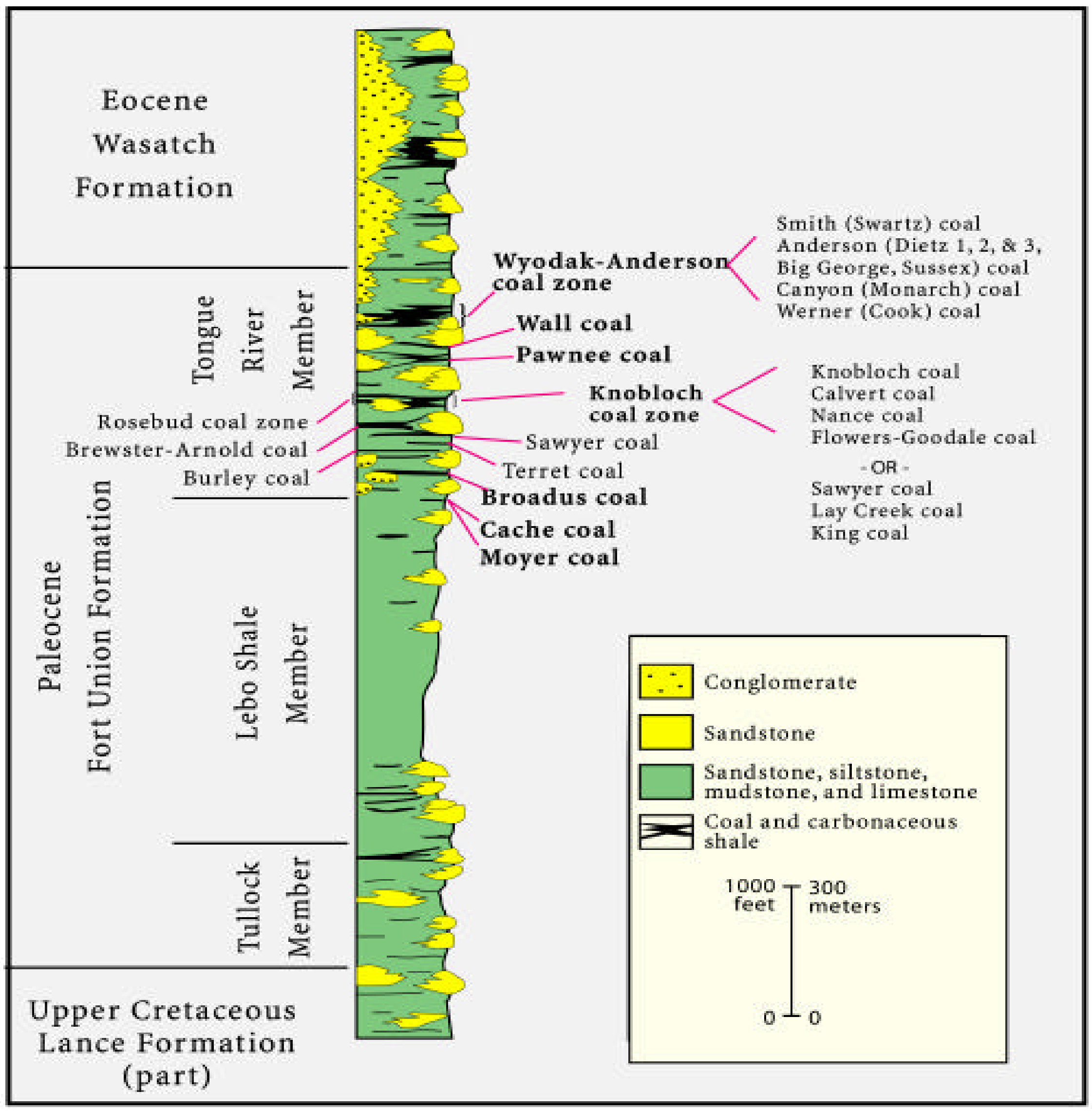
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana
RMP Areas: BLM Miles City Field Office.
Water Well Locations: Montana Bureau of Mines & Geology Water Well Database.
CBM Potential: 1:250,000 scale, Geologic Map 60, Montana Bureau of Mines & Geology.

Exhibit 13 is a stratigraphic column of Upper Cretaceous and Lower Tertiary sediments in the Montana PRB. The stratigraphic column shows the continuous development of several thousand feet of sediments that include widespread sands, coals and fluvial, fine-grained sediments. The major formations are named along with major coal seams that are discussed in greater detail throughout the report. The basin's surface consists largely of the several members of the Paleocene Fort Union Formation, as well as the overlying Wasatch Formation in a small corner of the basin (Rice et al. 2000).

The Fort Union Formation encloses the various coal seams within the Montana portion of the PRB; these coals function as the source of the CBM, as well as aquifers carrying groundwater of varying quantity and quality. In the PRB coals range in depth from the surface to approximately 900 feet deep. Coals vary in thickness from over 50 feet and can form aggregate thicknesses over 100 feet. Coal seams in the Fort Union do not have significant matrix porosity and permeability (Gray 1987); they can act as aquifers because fluids such as water and methane are contained within the coal's fracture system, known as cleat (Montgomery et al. 2001). The fractures accumulate the fluids and allow the fluids to move horizontally and vertically.

EXHIBIT 13 - STRATIGRAPHIC COLUMN OF UPPER CRETACEOUS AND LOWER TERTIARY SEDIMENTS IN THE POWDER RIVER BASIN

Bedrock units that fill the PRB include the Lance, Fort Union, and Wasatch Formations (Rice et al. 2000).



Deep Formations

A number of regional stratigraphic units occur beneath the major basin fill units within the PRB. These formations are broadly present across Montana including the PRB. Penetrations of these formations by conventional oil and gas wells have been few and hydrocarbon production is scattered. The Cretaceous age Judith River, Shannon, Eagle, and Dakota/Lakota Formations are present in the subsurface between approximately 2,200 feet below ground surface (bgs) and 9,000 feet bgs. These four sandy formations are encased and overlain by thick Cretaceous shales of the Colorado and Pierre Formations (Noble et al, 1982). Reservoir quality sands are not present everywhere within each of these formations but each could locally be a suitable disposal zone for produced CBM water. In addition, the shales of the Colorado and Pierre Formations could perhaps accept produced water under injection pressures higher than fracture pressure. Only the Shannon Formation produces gas within the PRB.

The Upper Cretaceous Eagle Formation carries coals in Blaine, Park, and Gallatin counties (Nobel et al. 1982). These coals are prospective for CBM resources but currently do not produce.

Upper Cretaceous Lance Formation (Locally Represented by the Hell Creek Formation and Fox Hills Formation)

The Hell Creek and Fox Hills sands are Late Cretaceous in age and underlay the Fort Union in the Montana Portion of the PRB. They are the sand equivalents of the predominantly shaley Lance Formation. The sands are difficult to separate in outcrop, very difficult to separate in the subsurface, and appear to be in hydrologic continuity. Together, the Hell Creek and Fox Hills total approximately 500 feet of non-marine coastal plain sediments that have been shed from the mountains to the east and west (Perry, 1962). They are made up of variable, shaley sands that contain some of the youngest dinosaur fossils in the world. The sands are scattered over most of Eastern Montana but are not present everywhere in the PRB; the sands outcrop at the edges of the basin and are found as deep as 3,700 feet bgs near the axis of the basin in Montana (Miller 1981). The Fox Hills Formation lies conformably upon approximately 2,000 feet of Upper Cretaceous Pierre Shale. The Hell Creek is overlain by the thick Tertiary Fort Union Formation.

Paleocene Fort Union Formation

The Fort Union forms most of the sedimentary fill within the Montana PRB. It consists of approximately 3,500 feet of non-marine silty and shaley clastics and coal beds whose individual thicknesses can be as much as 37 feet near the Decker mine (Roberts et al, 1999a). The Fort Union also contains clinker deposits, formed by the natural burning of coal beds and the resultant baking or fusing of clayey strata overlying the burning coal, which are present throughout much of the area and can be more than 125 feet thick (Tudor, 1975). Stratigraphically the clinker bodies are part of the Fort Union but the clinker is a lithological unit composed of baked and fused siltstone, clay, and sandstone units that have undergone diagenetic changes during the combustion of the coal within the past 3.0 million years (Heffern et al, 1993).

Individual units within the Fort Union that were formed as fluvial deposits could be expected to have lithological flow-units oriented in a dip-wise fashion. This preferred direction of porosity and permeability could be exhibited by directional variations in groundwater drawdown levels. The coals, however, appear to have been deposited in mires situated above or below drainage levels within erosional channel features or perched above these channels in raised bogs (Ellis, 1998). Some of the coals, therefore, could exhibit linear permeability phenomena while other accumulations may be isolated lenses unconnected with other coal seams. In developing CBM fields, it will be valuable to identify these different coal bodies, but such research is beyond the scope of this report.

The Fort Union is split into three stratigraphic members: the lowest being the Tullock Member, overlain by the Lebo Shale Member, overlain by the Tongue River Member (McLellan et al. 1990). In the Montana portion of the PRB, the bulk of the coals are confined to the Tongue River Member, while the Lebo and Tullock Members are predominantly shale and shaley sand (McLellan et al. 1990). The Members are discussed in detail below:

THE TULLOCK MEMBER:

This is the stratigraphically lowest part of the Fort Union, consisting of approximately 300 feet to more than 500 feet of interbedded sands and shales with minor coals near the base (Tudor 1975). The Tullock rests unconformably upon the Upper Cretaceous Hell Creek Formation throughout the PRB. While generally sandier, the Tullock is difficult to separate in outcrop and in the subsurface from the overlying Lebo Member.

THE LEBO MEMBER:

This middle member ranges from 75 feet to more than 200 feet of claystones, limestones, and mudstones with the Big Dirty coal (3 to 13 feet of thickness) at the very base (Tudor 1975). The Lebo is, in part, stratigraphically equivalent with the overlying Tongue River (McLellan 1990).

THE TONGUE RIVER MEMBER:

The thickness of the Tongue River varies from 750 feet at the outcrop edge near the fringe of the basin to 3,000 feet near the axis of the basin (Williams 2001). Total coal isopach ranges up to approximately 150 feet (Ellis et al. 1999). The Tongue River Member is divided into three units. The lower unit includes that portion below the Sawyer coal seam. The Middle unit includes the Sawyer through the Wall coal seam. The Upper unit includes that portion above the Wall coal seam (Ellis et al. 1999).

The Lower Tongue River unit is present across most of the Montana portion of the basin. It includes, from the base up, the Stag, Terret, Witham, Robinson, Rosebud-McKay, Flowers-Goodale, Nance, Calvert, and Knoblach coals. In the Ashland coalfield, the Lower Tongue River unit is up to 1,660 feet in thickness, and individual coals can be up to 71 feet thick (Roberts et al. 1999b).

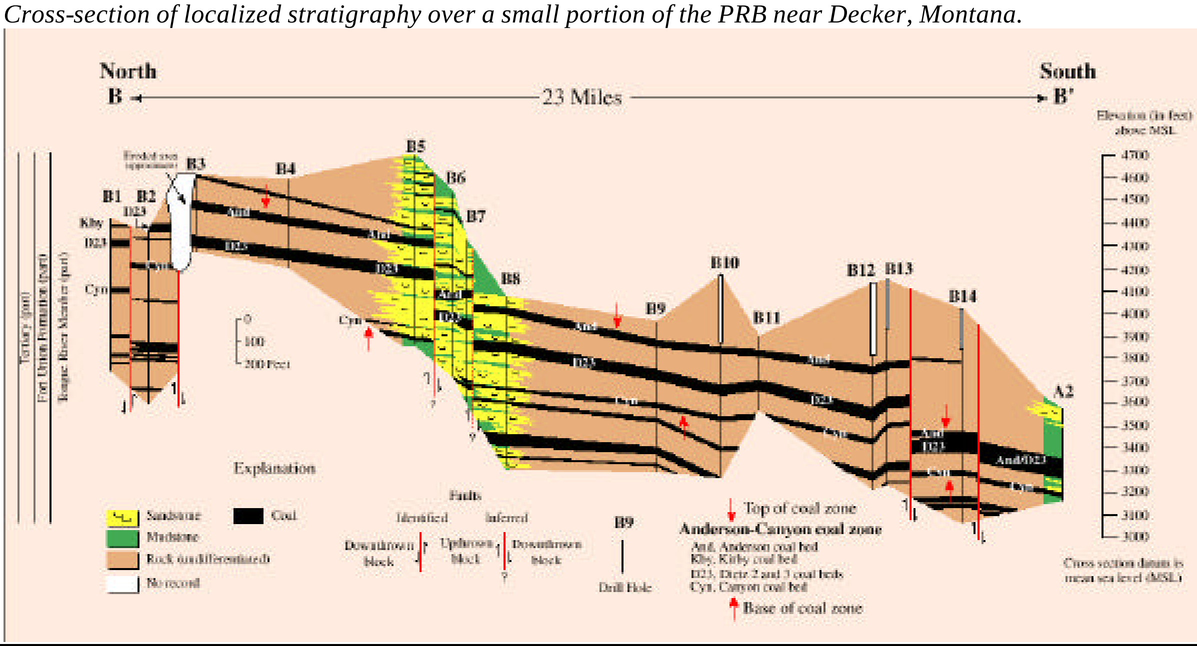
The Middle Tongue River unit is present over a large part of the Montana portion of the PRB. It includes, from the base up, the Sawyer, Mackin-Walker, Cache, Odell, Brewster-Arnold, Pawnee, and Wall coals.

The Upper Tongue River unit is present only in the southern part of the Montana portion of the PRB. It includes, from the base up, the Otter, Cook, Carney, Canyon, Dietz, Anderson, and Smith coals. At the Decker mine, the Upper Tongue River is up to 1,500 feet thick; coals can attain an individual thickness of 57 feet and an aggregate thickness up to 111 feet (Roberts 1999a).

Although coals are the most economically significant part of the Tongue River Member, they form a small portion of the sedimentary volume. They are also extremely variable stratigraphically, as shown in the cross-section depicted in Exhibit 14. Exhibit 14 shows stratigraphic variation of the Anderson-Canyon Coals in the area of the Decker Mine, Powder River Basin, Montana.

EXHIBIT 14 - STRATIGRAPHIC VARIATION OF THE ANDERSON-CANYON COALS IN THE AREA OF THE DECKER MINE, POWDER RIVER BASIN, MONTANA (ROBERTS ET AL, 1999A)

Cross-section of localized stratigraphy over a small portion of the PRB near Decker, Montana.



Note: this cross-section reflects localized stratigraphy over a small portion of the Powder River Basin and is not intended to be a regional reflection of the entire Montana portion of the basin.

The cross-section illustrates the continuity or lack of continuity within the stratigraphic units. Coal aquifers can be seen to have local continuity but lack regional continuity. A local coal seam such as Dietz 1 can persist for several miles but the entire Anderson-Dietz package is eroded from the Colstrip area. The stratigraphic complications documented in Exhibit 14 suggest that even thinly separated coal seams may be very dissimilar. The cross-section illustrates the pinch-outs of coal seams, bifurcating coal seams, and erosional cut-off of coal seams by Paleocene and recent stream erosion. All of these factors can play a role in complicating the production of water and methane from the Fort Union Formation.

Fort Union coals are also present in the Big Horn Basin, the Bull Mountain Basin, and Park and Gallatin counties where they are prospective for CBM resources.

Wasatch Formation

The Eocene Age Wasatch is present in the Montana portion of the PRB as fine-to medium-grained sandstone lenses and channel-fill interbedded with silstones, shales, and minor coal. The thickness of the Wasatch Formation ranges from near zero at the outcrop edge to 400 feet near the southern state boundary (Roberts et al. 1999a). It is present in outcrop in the extreme southwest corner of the basin where it overlies the Fort Union.

Quaternary Alluvium

Quaternary age sediments are those that are Pleistocene (the latest glacial episode) and Recent (post-glacial episode) in age; the sequence is dominated by events and effects associated with continental glaciation, including glacial till and exaggerated peri-glacial valley fill. Quaternary sediments in the PRB and most of the state are present as variable fill in stream and river valleys. Quaternary Alluvium consists of unconsolidated sand, silt, and gravel that make up the floodplains and stream terraces of creek valleys in the PRB (BLM 1999b). Thickness is highly variable, but maximum thickness is not expected to exceed 90 feet. Lithology is somewhat dependent on bedrock outcrop; alluvium overlying the Tertiary strata are mostly fine-grained to medium-grained sands and silts. Coarser-grained alluvium may be associated with some of the larger rivers where provenance has been outside the PRB (Hodson et al. 1973). Alluvium aquifers are largely unconfined and connected to active river flow. Because alluvial aquifers can deliver large quantities of water to water supply wells, they are important stratigraphic features. They are also important to this report because they are vulnerable to impact and are often connected to surface water resources. Alluvial aquifers can be impacted by surface activity and can act as a conduit to carry those impacts to valuable surface water resources.

HYDROLOGY

Hydrology identifies aquifers (porous units containing water) and aquitards (non-porous strata that serve to confine and separate aquifers) in a geographic and vertical sense. Aquifers can contain drinkable water, brackish water of limited usability, or salt water. In the EIS planning area, several formations contain drinking water but show variable reservoir quality and water quality. The Montana portion of the PRB includes many aquifers that represent different hydrologic flow regimes. The basin includes unconfined aquifers as well as confined, bedrock aquifers. Aquifers range from the unconfined Quaternary alluvium in the streambeds of rivers and creeks to the Mississippian Age Madison Formation in excess of 10,000 feet below the surface. The water quality within these aquifers ranges from less than 300 mg/L TDS to more than 30,000 mg/L TDS (Bergantino 1980). The aquifers also vary in depth from the basin center to the margin. Coal aquifers are widespread, supply large numbers of water wells, and will be impacted most by CBM production.

Exhibit 15 lists the significant aquifers in the Montana portion of the PRB that will be discussed throughout this report. The wells are almost exclusively completed in the shallow aquifers (< 500 ft depth) with the Tongue River Coals being the major aquifers. Wells completed in the major aquifers are limited in geographic distribution – Alluvium wells are distributed along principle rivers and streams, coal wells are arrayed in two principal bands corresponding to two stratigraphic packages, and Cretaceous sand wells are largely limited to the rim of the PRB. Only a very few wells utilize the Wasatch Formation, an aquifer that is more widespread and more important in the southern part of the PRB. A small number of wells near the edges of the PRB use the Cretaceous aquifers. A few wells utilize the sands in the Lebo and Tullock Members. The majority of water wells are completed in the Tongue River coals. The coal aquifers are the most important to this report since they hold the CBM resource and production of the gas will directly impact coal seam aquifers. CBM production inevitably impacts coal seam aquifers within and around CBM producing fields. CBM production may also impact Alluvium aquifers where they intersect impacted coal seams.

EXHIBIT 15 - AQUIFERS IN THE MONTANA PORTION OF THE PRB

Summary of Montana PRB aquifers and associated data for approximate depth and number of current wells listed in the MBMG database.

AGE	AQUIFER	APPROXIMATE DEPTH	NUMBER OF WELLS IN THE MBMG DATABASE
Quaternary and Recent	Quaternary Alluvium	Surface to 90 feet	198
Tertiary	Wasatch	100 feet	6
	Tongue River Coals	50 to 400 feet	957
	Lebo/Tulloch	100 to 400 feet	306
Cretaceous	Hell Creek/Fox Hills	100 to 500 feet	199
	Judith River	2500 feet	1
	Eagle	2700 to 5700 feet	0
	Dakota/Lakota	5600 to 8600 feet	0

Note: MBMG = Montana Bureau of Mines and Geology

Dakota/Lakota Formation

This formation is present at approximately 5,600 feet bgs in the northern part of the PRB and at approximately 8,900 feet bgs at the southern Montana state line. The Dakota is present across the basin and commonly contains more than 50 feet of sand.

Eagle Formation

This sand zone is present at the south edge of the Montana portion of the PRB at approximately 5,700 feet bgs and at approximately 2,700 feet bgs on the northern edge of the basin. The Eagle exhibits scattered sand development. In Gallatin, Park, and Blaine counties, the Eagle Formation contains coal seams; in these counties CBM production may impact the Eagle sand aquifers.

Judith River Formation

This formation shows in excess of 40 feet of total sand at a depth of approximately 2,150 feet bgs near the Ashland coal area at the northern edge of the PRB. Sand in this formation is not present everywhere and produces water of only moderate quality; water of this quality could not be used for drinking or irrigation without treatment.

Fox Hills—Hell Creek Formations

These Cretaceous sands combine to form the principal aquifer in southeastern Montana (Miller 1981). Water wells into the joined sands can yield as much as 40 gpm. Municipal supply wells can yield more than 200 gpm (Miller 1981). Water quality is generally lower than in either the Fort Union or Quaternary Alluvium. The Fox Hills/Hell Creek aquifer is separated from the coal aquifers in the Fort Union by over 500 feet of fine-grained sediments in the Tullock and Lebo Members; these aquitards are not penetrated by CBM development wells and will, therefore, maintain their integrity. CBM production and drawdown of coal aquifers will not impact water wells using these Cretaceous or deeper aquifers.

Fort Union Formation

The Fort Union Formation contains minor sands and all of the water producing coal beds in the Montana PRB. Coal beds are the most-used aquifers in the Montana PRB (MBMG 2001) where they are largely used for stock watering. Yields can be as high as 150 gpm but average approximately 10 gpm (Bergantino 1980). Within the PRB, coalbed water wells are often less than 100 feet deep but can be as deep as approximately 400 feet (MBMG 2001). Coal reservoir parameters are listed in Exhibit 16 below. The thickness information provided appears to be highly variable but this may not be the truth; previous analysis may have combined thinner coal seams that are separated by thin shale layers that form local aquitards, but appear to be minor lenses in cores or wire-line logs. Porosity data is largely a measure of fracture porosity that is notoriously difficult to measure. The other parameters listed are also dependent upon fracture or cleat density. A more basic uncertainty is the unknown influence of coal bed methane on reservoir characteristics – is there a genetic connection between reservoir parameters and the presence of significant quantities of methane? Do the same coal seams, in a non-producing condition, have significantly different characteristics? There is insufficient data in the Montana portion of the PRB to provide answers. CBM produced water will be discussed in more detail within the impacts chapter of this Technical Report.

EXHIBIT 16 - PUBLISHED RESERVOIR PARAMETERS FOR ACTUAL AND POTENTIAL CBM RESERVOIRS

Reservoir parameters for several coal bed aquifers throughout the Montana portion of the PRB as compared to the Wyodak-Anderson Wyoming EIS data.

COAL SEAM	THICKNESS	TRANS-MISSIVITY	HYDR. COND.	POROSITY (%)	STORAGE COEFF.
Anderson – Dietz (CX Ranch) Redstone 1999	70’	300 ft^2/day	3.37 ft/day	2.0	2.18E-5
Knobloch (Montco Mine, permitted but not opened) (MDSL, 1982)	44’	58 ft^2/day	2.3 ft/ day	2.0	1.2E-4
Knobloch (Ashland Mine, not permitted) (Woessner, et al, 1981. EPA-600-7-81-004a.)	54’	100 ft^2/day	2 ft/day	2.0	5.0E-5
Wyodak-Anderson (BLM, 1999a) For comparison only	Variable		2.0E-5 m/sec (5.67 ft/day)	1.0	1.0E-4

Groundwater conditions described for the Montana Portion of the PRB Resource Management Area (RMA) also exist within the Bull Mountains Basin in the Billings RMP area (Noble 1982). In this basin, Quaternary Alluvium and shallow Fort Union Formation coal and sand aquifers are important sources of water. Coals in the Billings RMP area are adjacent to sand aquifers and are aquifers themselves; water production from Bull Mountains Basin coals is likely to cause drawdown to nearby water wells similar to the Montana portion of the PRB in addition to possibly impacting vertically adjacent aquifers.

Wasatch Formation

Only a very small portion of the Montana PRB contains Wasatch bedrock; the formation has been either eroded or was not deposited over most of the area except within the very center of the basin. In the Wyoming portion of the PRB, Wasatch sands are significant aquifers that can support wells that yield in excess of 500 gpm (BLM 1999b).

Quaternary Alluvium and Associated Terrace Deposits

These clastic sediments are unconfined and in connection with permanent or significant ephemeral rivers and streams. Thickness can exceed 90 feet, but most average less than 30 feet (Bergantino 1980). Water yields average 25 gpm, but can be considerably higher (Bergantino 1980). Quaternary alluvium is the most-used aquifer in the Great Plains portion of Montana (Noble et al. 1982). In the Montana PRB, a total of 198 wells are identified as being screened in the Quaternary Alluvium (MBMG 2001). These wells are largely used for domestic supply, but are also used for publicly owned water systems, livestock, and irrigation. In the Montana PRB, Fort Union Formation coals outcrop in the valleys of streams and are in contact with alluvium. At the edge of the basin, Lebo and Tullock aquifers, as well as Cretaceous aquifers, outcrop in streambeds.

WATER WELLS

Exhibit 17 is a water well map of the Montana portion of the PRB. Not all wells plotted in Exhibit 12 are identified on this map because owners have not reported information on all water wells to the state. Wells completed in the major aquifers are limited in geographic distribution:

- Alluvium wells are distributed along principle rivers and streams although several wells identified as alluvium appear away from present streams; these are either misidentified or are completed in alluvial deposits associated with abandoned, dry stream valleys.
- Coal wells arrayed in two principal bands corresponding to two stratigraphic packages – the Anderson-Dietz at the top of the Tongue River Member and limited to the center of the basin, and the Knoblock at the base of the Tongue River Member and occurring throughout most of the basin.
- Lebo and Tullock wells appear mostly beyond the outcrop of the Tongue River Member beyond which no coals are present in the subsurface.
- Cretaceous sand wells largely limited to the rim of the PRB where they are shallowest.

The coal aquifers are of special interest since they hold the CBM resource and production of the gas will directly impact coal seam aquifers. CBM production inevitably impacts coal seam aquifers. CBM production may also impact Alluvium aquifers where they intersect coal seams. The most important groundwater-surface water interaction concerning the effects of CBM production is the exchange of water between coal seams and surface water via Alluvium. Exhibit 18 is a map of coal and clinker deposits in the Montana portion of the PRB. Several bands of coal seam development – Anderson, Knoblock, and Colstrip – outcrop as clinker in the watersheds of major streams. These clinkers often give rise to springs that feed into rivers and alluvium. During periods of little run off, such as late winter when streams and rivers are at baseflow, streams are particularly vulnerable to impact from surface recharge by low quality coal aquifer water. At times of high run off, rivers and streams often have sufficient flow to dilute the coal aquifer water coming via clinker-fed springs.

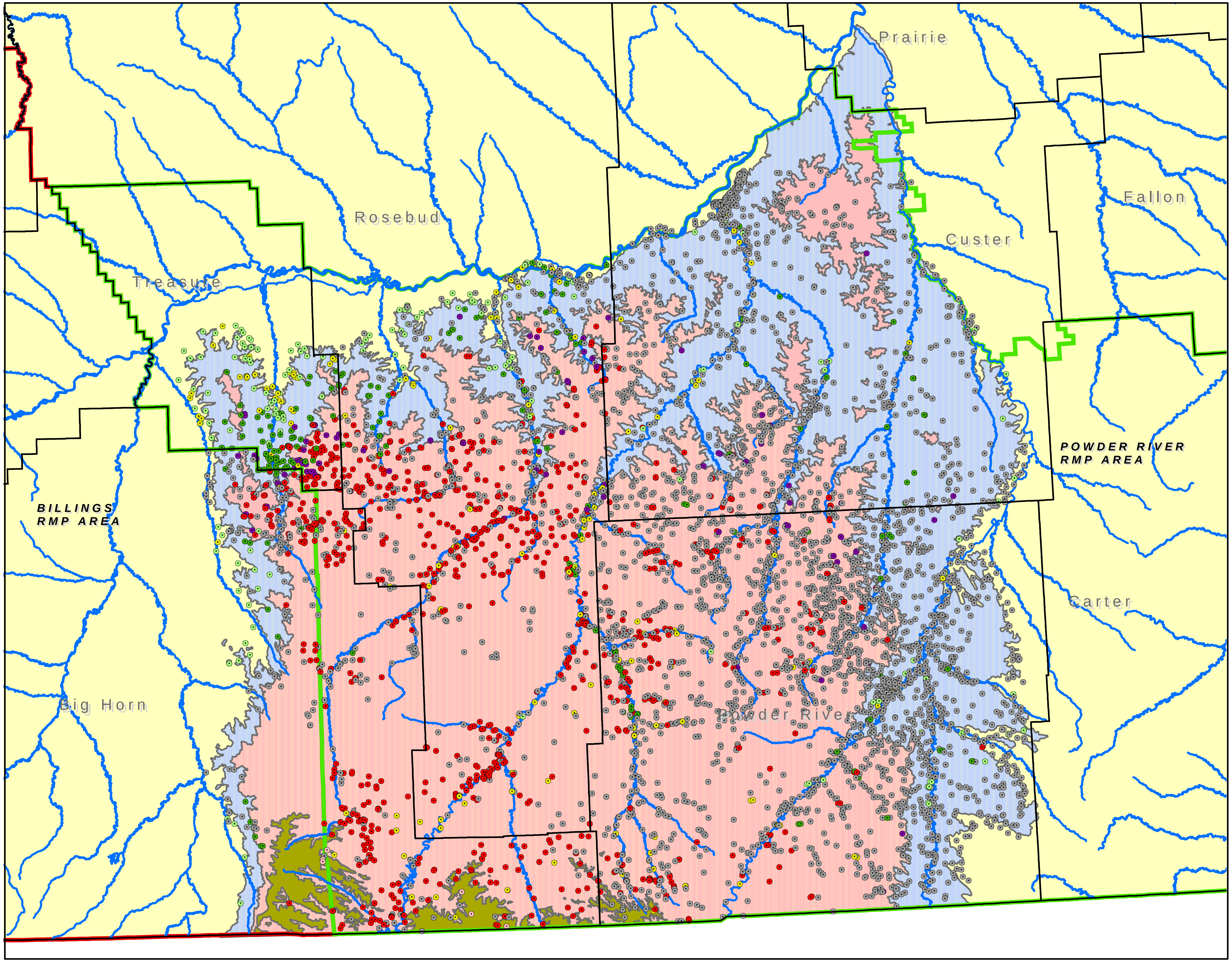
ARTIFICIAL PENETRATIONS

Artificial penetrations including geotechnical boreholes, unplugged oil and gas wells, seismic shot-holes, or open water wells are able to conduct water from the surface into aquifers or can conduct water between aquifers. A penetration open to an aquifer and to the surface can allow low quality surface water (CBM water being discharged to an impoundment or water running off cropland laden with fertilizers and pesticides) to enter the aquifer. A penetration open to more than one aquifer can allow water to flow between the aquifers; if one of the aquifers is being produced for CBM, the coal seam could act as a sink to steal water from the other open aquifer. Open artificial penetrations are a difficult threat to gauge and predict; isolated, forgotten water wells can occur anywhere. Oil and gas wells drilled prior to state casing and plugging regulations are a threat that can be more easily predicted. Artificial penetrations are likely a remote threat to water resources in the PRB but are perhaps an important consideration elsewhere in the state. If, during CBM productions, an open borehole were discovered, it would be the responsibility of the original owner of the borehole or the CBM operator to suitably plug the hole.

WATERSHEDS

Watersheds are important to predicting the impacts from CBM development in Montana. Water resource factors such as water quality, water use, and potential impacts will be discussed throughout this report in terms of watersheds. Each watershed is drained by a single stream or river and each is bounded by a no-flow topographic boundary. Streams and rivers are profoundly influenced by their watersheds; in particular water volume and water quality vary from base flow conditions to high-flow conditions under the control of runoff from land surfaces and recharge to rivers by aquifers. Exhibit 3 in Chapter 1 highlights the watersheds in the PRB along with potential CBM areas. The areas of highest potential for CBM development fall within the northern portion of the Upper Tongue River Watershed, the southern section of the Lower Tongue River Watershed, the western section of the Middle Powder River Watershed, and the eastern section of the Rosebud Watershed. The current CBM production area in the Montana PRB lies within the Upper Tongue River Watershed. It should be noted that the watersheds along the southern boundary of the Montana PRB drain to the north and may already be impacted by CBM development in Wyoming. Exhibit 19 likewise highlights watersheds in the Billings RMP area. The areas of highest potential for CBM development fall within the northern section of the Upper Yellowstone-Pompeys Pillar Basin, the eastern Upper Musselshell Watershed, and the southern Middle Musselshell Watershed.

Exhibit 17: Water Well Aquifer Use Map of the Montana Portion of the Powder River Basin



Legend

Rivers

Aquifer

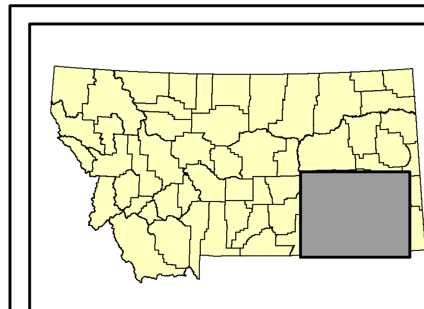
- Alluvium
- Wasatch Fm.
- Lebo Mbr.
- Tongue River Mbr.
- Tullock Mbr.
- Cretaceous
- Unknown

Powder River RMP Area

Billings RMP Area

GEOLOGY

- Wasatch Fm.
- Tongue River Mbr.
- Lebo / Tullock Mbrs.



Location Map

Date Prepared: April 2, 2001

Prepared by: J. Patton

Project Mgr.: D. Arthur

N W E S

1:890,000

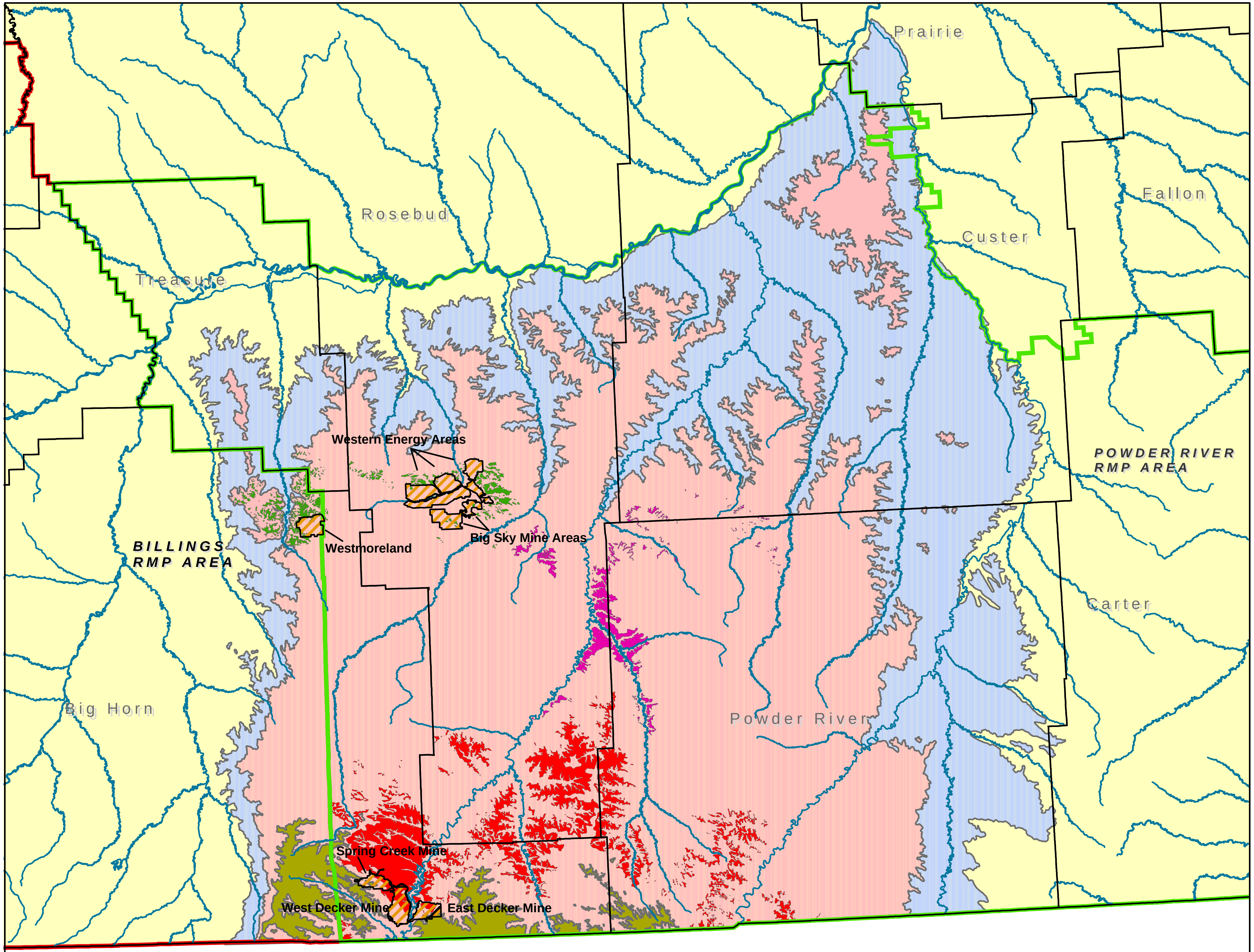
20 10 0 20 Miles

20,000 10,000 0 20,000 40,000 Meters

DATA SOURCES

Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Reservations: 1:100,000 scale, reservations, Montana State Library/NRIS, Helena, Montana
RMP Areas: BLM Miles City Field Office.
Geology: 1:250,000 scale, 1999, USGS Professional Paper 1625a.
Water Well Locations: Montana Bureau of Mines & Geology Water Well Database.

Exhibit 18: Map of Coal and Clinker Deposits Montana Portion of Powder River Basin

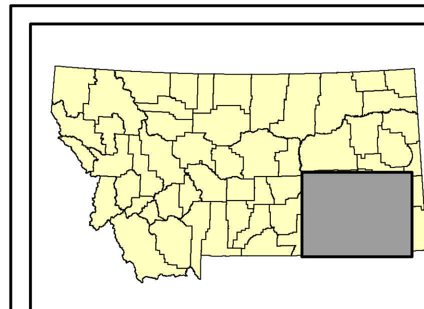


Legend

- Rivers
- Powder River RMP Area
- Billings RMP Area
- Coal Mines
- Wyodak - Anderson Coal Clinker
- Knoblock Coal Clinker
- Colstrip Coalfield Clinker

GEOLOGY

- Wasatch Fm.
- Tongue River Mbr.
- Lebo / Tullock Mbrs.

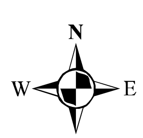


Location Map

Date Prepared: April 2, 2001

Prepared by: J. Patton

Project Mgr.: D. Arthur



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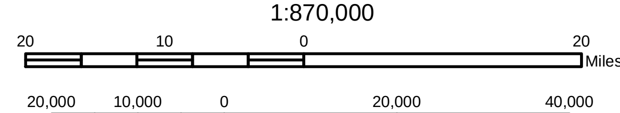
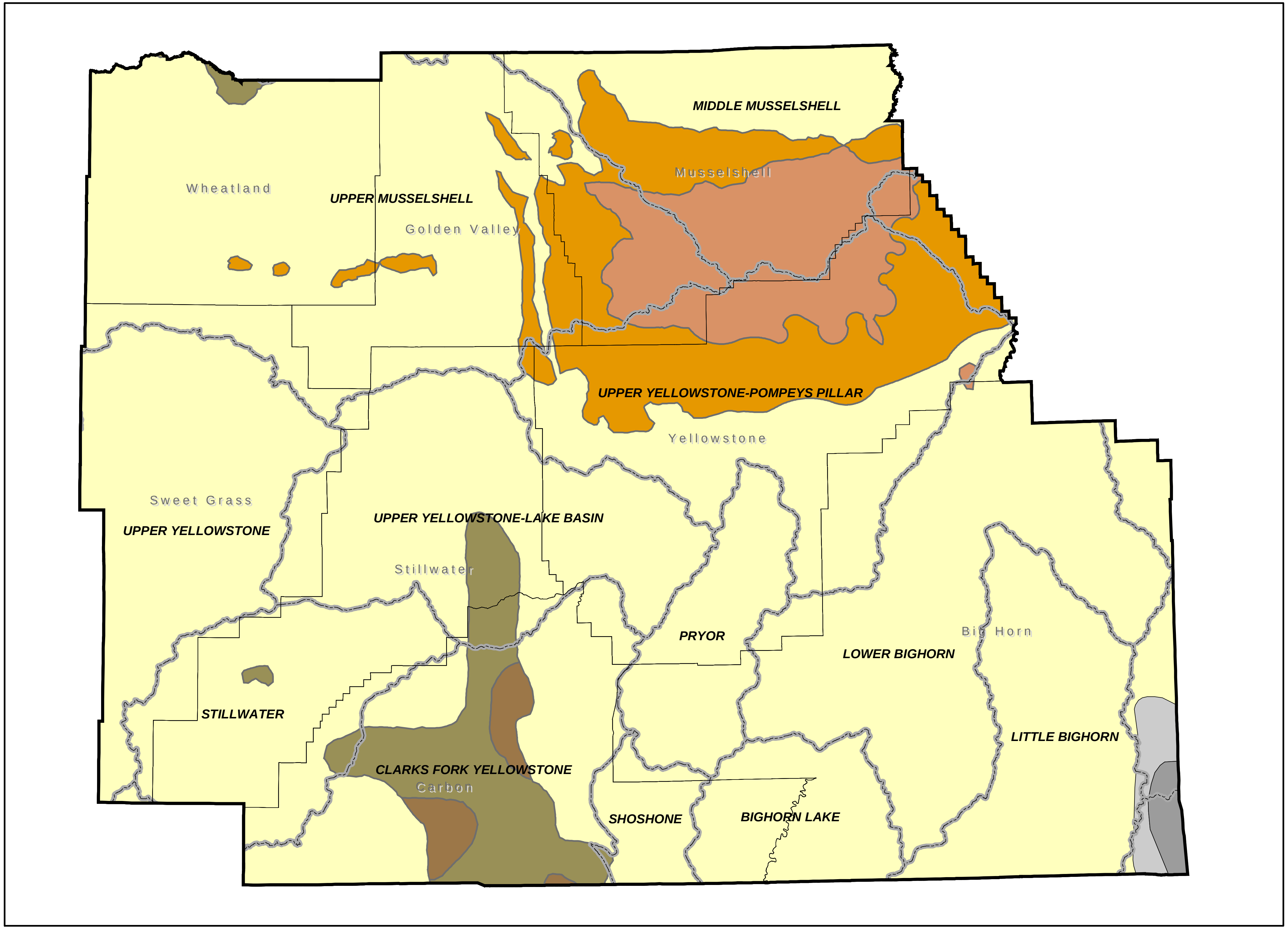


DATA SOURCES

Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana
Rivers: 1:100,000 scale, rivers, Montana State Library/NRIS, Helena, Montana
RMP Areas: BLM Miles City Field Office.
Geology and Coal: 1:250,000 scale, 1999, USGS Professional Paper 1625a.
Coal Mine Boundaries: Montana Bureau of Mines & Geology

Exhibit 19: Billings RMP Area showing Watersheds, Coal, and CBM Potential



Legend

Watershed Boundaries

CBM POTENIAL

Higher

Lower

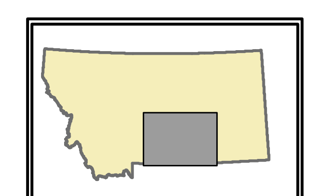
GENERALIZED COAL RANK

M-H Volatile Bituminous

M-H Volatile Bituminous of doubtful value

Sub-Bituminous

Sub-Bituminous of doubtful value



Date Prepared:

Prepared By: J. Patton

Project Mgr.: D. Arthur

1:1,000,000

20,000 10,000 0 20,000 Meters

10 5 0 10 Miles

DATA SOURCES
Counties: 1:100,000 scale, counties, Montana State Library/NRIS, Helena, Montana.
Watersheds: 1:100,000 scale, watershed boundaries, Montana State Library/NRIS, Helena, Montana.
Coal Occurence: Tully, 1996.

NOTE: To be used as a reference graphic only. Some data represented are at scales greater than it's source.